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Coordinated multi-point joint transmission evaluation in heterogenous cloud radio access networks

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Abstract— **In this paper, the effect of applying coordinated multi-point joint transmission (CoMP-JT) in system performance of 5G heterogeneous cloud radio access networks (H-CRANs) is investigated. For this purpose, two simple user-centric and network-centric clustering methods are presented and the amount of obtained CoMP gain in each of these dynamic-formed clusters is evaluated. Network-centric and user-centric clustering approaches are also compared with each other with respect to imposed cell load and system performance metrics through different simulation setups. The results demonstrate that remarkable improvement could be achieved specially by user-centric clustering at the price of higher imposed load and lower energy efficiency disadvantages.**

Keywords-heterogenous cloud radio access network, coordinated multi-point joint transmission, clustering.

I. INTRODUCTION

In recent years, data traffic has experienced record growth among the world's operators as demands for mobile and wireless services are exponentially increasing [1]. In such services the service quality and speed of data transfer are key concepts should get profound improved. To achieve these goals, 5G networks with revolutionary approaches and based on heterogonous topology have emerged [2]. In this paradigm shift, subscribers are served by different level of access points (AP) which can be normally classified into high-power nodes (HPN) in macro-cells and lower-power nodes (LPN) in small-cells.

Interference mitigation through advanced signal processing techniques is of great significance to fully exploit the potential of HetNets. Coordinated multi point joint transmission (CoMP-JT) is a promising technology to achieve required data rate for cell-edge users by exchanging the interference signals to useful ones [3]. In this technology a set of coordinated APs which are clustered together serve one user simultaneously over the same physical resource blocks (PRBs). Besides, as it is investigated in [4], the improvement achieved by coordinating more than 4 cells is negligible comparing to the imposed complexity and signaling overhead. This raises the question that which cluster formation will lead to a more efficient CoMP-JT implementation. Generally, in comparison to static clustering, dynamic approach which applies real-time cluster reconfiguration by perceiving the condition of users at each time-instant, leads to higher improvement at the price of higher complexity [5]. Dynamic clusters can be formed either in a network-centric or a user-centric manner [6]. In network-centric scheme, CoMP clusters are non-overlapped and all users in the cluster coverage area are served by all APs belonging to the cluster. In contrast, in user-centric approach which is more complex, CoMP clusters can have overlap and each user has its own cluster.

Unfortunately, CoMP-JT has disadvantages in practical cellular networks in terms of imposed overload to the system and also degradation in performance gain as the density of LPNs increases. As a consequence, inspired by software defined wired network (SDWN), heterogeneous cloud radio access networks (H-CRAN) are recently proposed as a prominent and cost-effective scheme for 5G wireless networks [7]. The motivation behind H-CRANs is to simplify LPNs by building connections between them and a central base-band-unit (BBU) pool to take advantage of cloud computing capabilities and make the CoMP-JT feasible.

The goal of this investigation is evaluating the effects of applying CoMP-JT technique on the performance of a H-CRAN architecture based network. To the best of our knowledge, the effect of clustering method on the system performance and the amount of CoMP gain is not studied so far. This motivates us to propose two simple algorithms for user-centric and network-centric clustering and evaluate the amount of improvement in the system performance as compared to the results of [8]. We also compare network-centric and user-centric clustering methods and analyze their pros and cons in terms of system performance metrics and cell load.

In this literature, an iterative network-centric clustering algorithm is presented in [9] for LTE networks. The proposed approach in mentioned paper is based on negotiation among base stations (BSs) on their obtained utilities. The significant advantage of this paper is its fully distributed scheme in which no additional signaling exchange is needed. Besides, in [10] beamforming problem are evaluated in a CoMP-enable HetNet in which each HPN and all distributed LPNs in its coverage area has formed a simple network-centric cluster. However, the proposed clustering configuration is not reasonable in dense LPN deployment networks. Meanwhile, authors in [11] present an energy efficient power allocation for HetNets in which CoMP-JT is applied for each user in a user-centric cluster containing nearest APs to the user. A more sophisticated user-centric clustering algorithm is proposed in [6] for a H-CRAN considering cluster size limitation and also cell load balancing. In this paper, dynamic clusters are constructed in centralized BBU pool based on highest signal to inference and noise ratio (SINR).

The rest of this paper is organized as follows. In Section II, our system model is presented. The proposed dynamic user-centric and network-centric clustering algorithms are introduced in Section IV. In Section V, we present results from our simulation before concluding in Section VI.

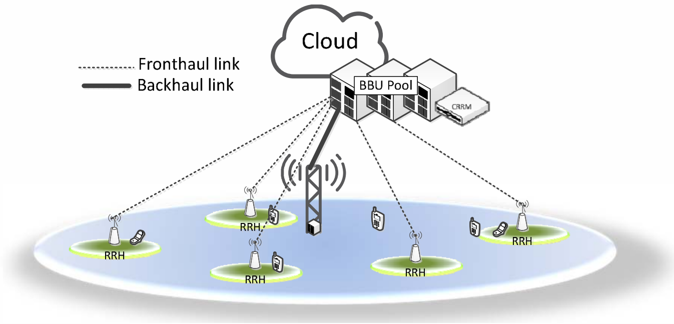
II. SYSTEM MODEL AND PROBLEM STATEMENT

We consider the CoMP-enabled H-CRAN as it is shown in Fig. 1, consisting of one BBU pool for centralized cooperative signal processing, one HPN or macro-eNode B (MeNB) at the center of one macro-cell responsible for delivering control signaling of all LPNs or radio remote heads (RRHs) and at the same time providing seamless coverage. Open access RRHs are also established in the coverage area of macro-cell to provide high data rate of users. As it is shown in Fig. 2, Users and RRHs are randomly distributed in the considered area according to a Poisson point process (PPP) distribution with parameters λ_U and λ_R respectively, where $\lambda_U \gg \lambda_R$. These users are considered to be static. Moreover, MeNB and each RRH are connected to the BBU pool through ideal optical fibers called backhaul and fronthaul, respectively. All open RRHs are also assumed to share the same radio resources with the MeNB. In addition, PRBs are allocated to different users associated to one AP using orthogonal frequency division multiple access (OFDMA). Furthermore, considering one cooperative radio resource manager (CRRM) at BBU pool, RRHs can coordinate with each other to serve users applying CoMP-JT technique. Furthermore, since our focus is on clustering problem, MeNB and RRHs are supposed to send their signals with their maximum transmitting power. The summary of system parameters are given in TAB. I.

Unlike the traditional HetNets, the intra-tier interference among dense RRHs in H-CRANs can be fully eliminated by large-scale cooperative processing through the BBU pool, while the inter-tier interference between RRHs and MeNB is severe and may degrade the quality of service (QoS) of some users. In this regard, CoMP-JT technology plays a key role in H-CRANs to cope with this QoS degradation.

TABLE I: SYSTEM PARAMETERS

Parameters	Definitions
$D \times D$	Macro-cell coverage area
λ_U	PPP user density
λ_R	PPP RRH density
$\mathcal{R}$	Set of all RRHs
B	Total available bandwidth at each AP
B_{PRB}	Bandwidth of one PRB
N_{PRB}	Total number of available PRBs in each AP
$L_{i,j}^R$	Path loss between user *i* and *j*th RRH
L_i^M	Path loss between user *i* and MeNB
p^M	Maximum affordable transmitting power at MeNB
p^R	Maximum affordable transmitting power at RRH
R_{th}	Minimum data-rate to satisfy a user
σ_n^2	Additive noise power



According to aforementioned assumptions, two scenarios of using and non-using CoMP-JT technology could be imagined to

Figure 1: The considered H-CRAN and its components

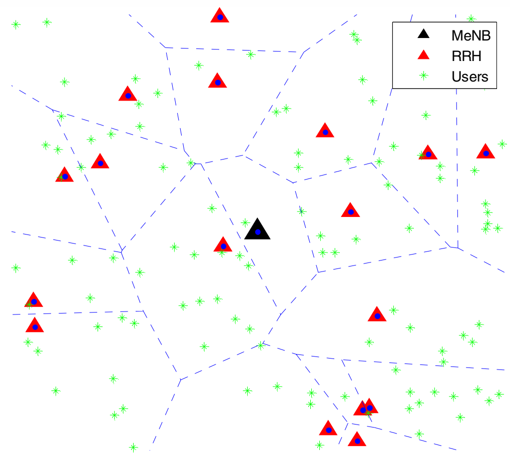


Figure 2: PPP distribution of RRHs and users

serve one user which are described as follow:

1) None-CoMP scenario: in this scenario, users are served with only one AP. Indeed, if *i*th none-CoMP user is associated to *j*th RRH, the received SINR at user side will be:

$$\gamma_{i,j}^{NC} = \frac{p^R / L_{i,j}^R}{p^M / L_i^M + \sigma_n^2} \tag{1}$$

Where p_i^M / L_i^M is the imposed interference from MeNB to user *i*.

On the other hand, the received SINR of user *i* when it is served by MeNB can be written as:

$$\gamma_{i,M}^{NC} = \frac{p^M / L_i^M}{I_i^{\mathcal{R}} + \sigma_n^2} \tag{2}$$

Where $I_i^{\mathcal{R}}$ is the total interference caused by all RRHs to this user and is equal to:

$$I_i^{\mathcal{R}} = \sum_{j \in \mathcal{R}} p^R / L_{i,j}^R \tag{3}$$

2) CoMP scenario: A user in CoMP scenario is the one whose required QoS cannot be satisfied by one RRH, which is called as CoMP-user throughout this paper. Thus, a group of RRHs which are clustered together provide service of such user simultaneously at the same PRBs. So the SINR level is enhanced. Indeed, if CoMP-user *i* is served by cluster C_k, the received SINR is given by:

$$\gamma_{i,C_k}^{CU} = \frac{\sum_{j\in C_k} p^R / L_{i,j}^R}{p^M / L_i^M + \sigma_n^2} \tag{4}$$

Generally, based on Shannon capacity theory, if user i receives SINR level equal to $\gamma_{i,j}^{AP}$ from AP k, its maximum achievable throughput is bounded to:

$$R_{i,k}^{AP} = \frac{B}{I_k}\log_2\left(1+\gamma_{i,k}^{AP}\right) \tag{5}$$

Where I_k is the number of associated users to AP k.

According to [12], unsatisfied users are designated based on their provided throughput as compared to a predetermined minimum data-rate threshold to be guaranteed. That is:

$$R_{i,k}^{AP} < R_{th} \tag{6}$$

III. Background and Motivation

One key advantage of H-CRAN is to decouple the control plane and user plane, such that RRHs are mainly used to provide high data rates with high energy efficiency performance, while the MeNB is deployed to guarantee seamless coverage and deliver the overall control signaling [7]. Therefore, the more offloading the MeNB from data traffic, the more benefit will be obtained from data and control plane decoupling.

From another point of view, one main problem of both HetNets and H-CRANs is that most of the users get their maximum SINR levels from HPN due to its much higher level of power as compared to RRHs. Consequently, most of the users are interested to be served by HPN even though they are closer to LPNs. To cope with this issue, cell range expansion with biasing technique has been emerged as the solution [2]. In this regard, authors in [8] propose a biasing-based user association method to offload MeNB from the traffic which in turn is shifted from MeNB to lower-loaded RRHs.

As we simulate the proposed algorithm in [8], which is shown in Fig. 3, applying biasing technique causes degradation in data rate of many of shifted users from MeNB to RRHs. Indeed, Fig. 3 indicates that the downlink throughput of many offloaded users are reduced to below a threshold value which is assumed to be 3Mbit/s in our simulations. So the target QoS of these users will not be satisfied after applying biasing technique, while serving by MeNB would satisfy them. The reason behind this fact is that user association strategy was taken based on biased level of SINR which is not actually equal to the received SINR at the user's side. This issue motivates us to incorporate CoMP-JT with the proposed biased strategy in [8] for these unsatisfied users to cope with their rate reduction by enhancing their received SINR level. In this case, not only MeNB is offloaded, but also the QoS degradation of most of the users can be compensated. With this in mind, two dynamic clustering algorithms are presented in next section which enables the network to improve SINR level of unsatisfied users.

IV. Dynamic Clustering Algorithms

Since the main goal of this paper is analyzing the amount of obtainable gains by applying CoMP-JT and also verifying the effects of clustering model in system performance, simple dynamic clustering schemes are evaluated in an inter-RRH coordinated network. More specific, two user-centric and network-centric clustering algorithms are proposed in this section. The size of all formed clusters is supposed to be fixed to M in these algorithms. Furthermore, considering the MeNB and the BBU pool, all information of users such as their channel state information is collected at BBU pool and correspondingly, cluster association decision for each user is centrally made at this load-aware centralized point.

A. User-centric clustering algorithm

In our user-centric approach, we assume each unsatisfied user to have its own CoMP cluster with size M. Indeed, the AP (either MeNB or RRH) which is associated to a typical user by the proposed biasing based algorithm in [8] will be coordinated with (M-1) other RRHs providing maximum SINR for this user. Consequently, we assume each CoMP-user to report its requested cluster involving M strongest candidate APs to BBU pool by the help of MeNB through ideal fiber backhaul. Accordingly, BBU pool sends user's data to each of the reported APs through unlimited fiber fronthaul. In turn, M coordinated APs afford the required service of this user over the same PRBs. Therefore, each AP can belong to more than one user-centric cluster.

The reason behind designing this simple algorithm is to configure user-centric clusters with low-level of complexity to minimize unsatisfied users and also analyze the advantages and

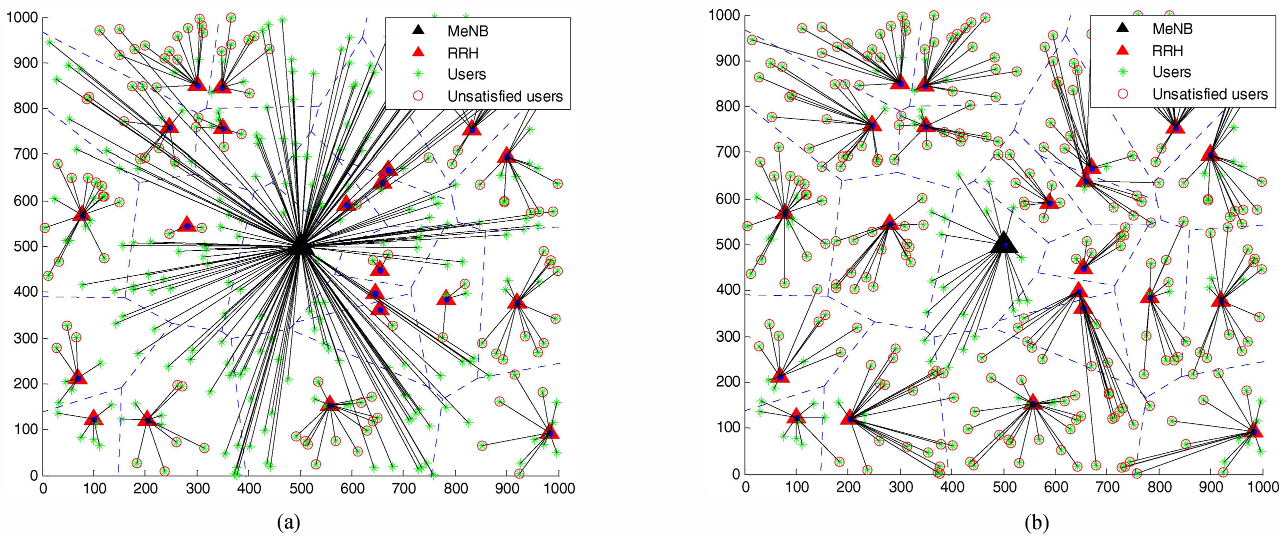


Figure 3: The effect of user association method proposed in [8] on offloading MeNB and the number of unsatisfied users. (a) user association based on maximum actual received capacity. (b) user association by the biasing-based algorithm proposed in [8].

disadvantages of even a simple user-centric algorithm regarding to system performance evaluation metrics.

B. Network-centric clustering algorithm

The main difference between network-centric clusters with user-centric ones is the none-overlap property. In other words, despite of user-centric clustering, each AP can belong to only one network-centric cluster. Therefore, in contrast to user-centric clusters, network-centric ones should be disjointed. In order to obtain the best possible network-centric clusters, it is needed to verify that the coordination of which APs will lead to the highest gain of CoMP-JT. Undoubtedly, a cluster which is observed more in users' reports has higher potential to exploit CoMP-JT benefits. So by forming the most requested clusters, the highest number of users would benefit from CoMP-JT. But due to the presumption of having disjointed network-centric clusters, simultaneous configuring of clusters with the maximum number of demands might be impossible. Considering these into account, the clustering decision must be taken in a way that the formed clusters are not only the maximum requested ones, but also have no common APs.

Assume that each AP has its own specific number and N_u unsatisfied users are located in one macro-cell. Let $N_u \times M$ matrix $\mathbf{X}$ denote the set of requested clusters by users in which each row involves the certificated numbers of M strongest APs reported by one user. Matrix $\mathbf{C}$ with dimension $N_u \times N_u$ is also defined as:

$$\mathbf{C}_{i,j} = \begin{cases} 0 & \mathbf{X}_i^{\mathrm{r}} \cap \mathbf{X}_j^{\mathrm{r}} \neq \varnothing \\ 1 & o.w. \end{cases} \quad \forall 1 \le i, j \le N_u \tag{7}$$

In which, the ith row of Matrix $\mathbf{X}$ is expressed as $\mathbf{X}_i^{\mathrm{r}}$, meaning that if cluster i has common RRH with cluster j, the corresponding element in matrix $\mathbf{C}$ would be zero. Otherwise it is equal to 1.

Moreover, let's consider vector $\mathbf{N}$ with N_u elements which shows the number of demand for each N_u requested clusters. Considering these assumptions, a step by step algorithm to form the network-centric clusters with the aforementioned goals can be described as follows:

1) Step1: Specify M as the cluster size and N_u as the number of CoMP-users. Also consider $\mathbf{C}_{\mathrm{NC}}$ to be initially null as the set of formed network-centric clusters and set all elements of demand vector $\mathbf{N}$ to be zero.

2) Step 2: Determine matrix $\mathbf{X}$ and also matrix $\mathbf{C}$ according to the requested clusters by users and (7), respectively.

3) Step 3: Rectify vector $\mathbf{N}$ based on demand number of each cluster. Also, find the repetitive rows of matrix $\mathbf{X}$ as duplicate cluster requests and set the corresponding value of duplicate ones in vector $\mathbf{N}$ to zero.

4) Step 4: Seek for the maximum value in vector $\mathbf{N}$ and add its corrsponding row in matrix $\mathbf{X}$ to $\mathbf{C}_{\mathrm{NC}}$ as the first formed cluster. Then modify vector $\mathbf{N}$ by setting the corresponding elemnt to zero.

5) Step 5: Find the corrsponding row $\mathbf{C}_i^{\mathrm{r}}$ of the formed cluster in Step 4 in matrix $\mathbf{C}$. Modify vector $\mathbf{N}$ as follow:

$$\mathbf{N} = \mathbf{N} * \mathbf{C}_i^{\mathrm{r}} \tag{8}$$

In which $*$ is the elementwise multiplier.

6) Step 6: Stop the algorithm if all elements of $\mathbf{N}$ are zero. Otherwise, go back to Step 4.

By implementing the described algorithm, the final network-centric clusters will be found in matrix $\mathbf{C}_{\mathrm{NC}}$.

C. Cell load definition

The imposed load to each RRH is a key concept which can affect the performance gain of CoMP-JT in H-CRANs in providing high data rate for users. In [12], the imposed load from a user to its serving cell is introduced as the proportion of PRB that should be utilized to provide minimum required data rate of user. In this regard, the number of required PRB to provide R_{th} for user i by its serving RRH k can be estimated as:

$$n_{i,k}^{AP} = \frac{R_{th}}{r_{i,k}^{AP}} \tag{9}$$

where $r_{i,k}^{AP}$ is the maximum achievable throughput for user i from serving AP k by allocating one PRB and is equal to:

$$r_{i,k}^{AP} = B_{PRB} \log_2\left(1 + \gamma_{i,k}^{AP}\right) \tag{10}$$

Thus, the imposed load from user i to AP k is mounted to:

$$l_{i,k}^{AP} = \frac{n_{i,k}^{AP}}{N_{PRB}} \tag{11}$$

In CoMP scenario, since data is simultaneously transmitted to a typical CoMP-user by multiple APs, the imposed load of user is also distributed among serving nodes. As it is developed in [6], the imposed load from one user to each AP belonging to user's cluster with size M can be expressed as:

$$l_{i,k}^{CoMP} = \frac{n_{i,k}^{AP}}{M \times N_{PRB}} \qquad 1 \le k \le M \tag{12}$$

In order to clarify (12), imagine to have one CoMP-user which is serving by M APs belonging to one cluster. Since this user is scheduled in all of these APs at the same time slot, each AP will virtually dedicate $\frac{1}{M}$ of each PRB to this user. As a consequence, one actual PRB is allocated to this user at the end by all serving APs. Hence, the number of virtual PRB required to be allocated to one user by one AP will be divided to the size of the cluster.

V. SIMULATION RESULTS

In this section we evaluate the performance gain obtained by applying CoMP-JT in a network based on H-CRAN architecture in comparison to the outcomes of [8]. In this regard, CoMP-JT is applied in user-centric and network-centric clusters formed by simulating the proposed algorithms. The advantages and disadvantages of user-centric clusters versus network-centric ones are also discussed regarding to performance metrics such as success coverage probability, average throughput per user, network energy efficiency and the load imposed to each AP. The results are obtained over 1000 runs and the corresponding 95% confidence intervals are also reported.

In our simulation setups, the location of MeNB is considered to be fixed at the middle of one $1\text{km} \times 1\text{km}$ macro-cell. We assume λ_R to be 20 and λ_U to be 100. Meanwhile, the propagation environment is modeled by considering path loss $L(d) = 34 + 40\log_{10}(d)$ for macro-cell area, path loss $L(d) = 37 + 30\log_{10}(d)$ for the coverage area of each RRH, and thermal noise with power of -104dBm. Meanwhile, MeNB and RRHs are assumed to transmit with their maximum power equal to 46dBm and 30dBm, respectively. The total available bandwidth for each AP considered to be B=20MHz which can be allocated to users over 100 PRBs, each has 180kHz bandwidth. It is also assumed that each CoMP-user is served by 3 coordinated APs in both user-centric and network-centric clusters.

The success coverage probability is the first performance metric which is evaluated in our simulations. Actually, this metric can be interpreted as the reverse of outage probability. Hence, it is defined as the probability that the target SINR of one randomly chosen user can be met, so that it can be covered in the network. As it can be inferred from Fig. 4, applied CoMP-JT can noticeably enhance the success coverage probability of the proposed user association scheme in [8] by increasing SINR value. Meanwhile, user-centric clustering approach has shown higher potential in improving system performance regarding success coverage probability. It should be noticed that enhancing SINR value directly leads to data rate improvement. As a result, Fig. 4 implicitly infers that the probability of satisfying required data-rate of a randomly chosen user is also increased by applying CoMP-JT specially in user-centric clusters.

Our second simulation setup is focused on energy efficiency performance investigation. Generally, energy efficiency can be represented as the number of transmitted bits by consuming one joule energy (bits/joule). Regarding to this definition, the effect of applying CoMP-JT in energy efficiency of H-CRANs is demonstrated in Fig. 5. It implies that main disadvantage of CoMP-JT is degrading the energy efficiency of the network. As it is deduced, network-centric clustering method leads to more reduction in this performance metric.

To evaluate the amount of improvement caused by applying CoMP-JT in users' QoS, the average affordable throughput level per user over user-centric and network-centric clusters are compared with corresponding value of none-CoMP scenario in [8]. As it is shown in Fig. 6, CoMP-JT can prepare the opportunity of providing much higher average data-rate for users. Also, Fig. 6 indicates that as compared to network-centric

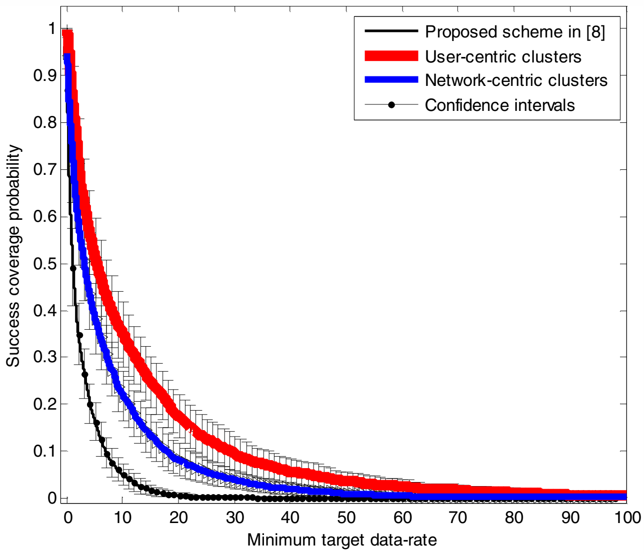


Figure 4: Success coverage probability evaluation

clusters, user-centric ones can enable the network to obtain considerably much throughput gain from applying CoMP-JT technology.

In order to give insight on the reason of such salient higher potential of user-centric clusters in enhancing the system spectral efficiency over network-centric ones, we compare the constructed clusters by both methods for a typical user in Fig. 7. It can be easily concluded from this figure that due to the near-far effect on the received SINR level at user side, the link of two other coordinated APs of the formed network-centric cluster to the user are such weak that make them unable to provide high capacity for the user. Thus, we call this user as victim one. While, this user is served by 3 highest link access to the network by forming user-centric clusters. Although, most requested clusters are configured network-wisely, users of this kind are not less. This fact leads to a reduction in the average provided throughput per user.

The last evaluated issue is the effect of CoMP-JT in the imposed load to each AP. To do so, the probability of the RRH to become overloaded versus the value of minimum target data-rate of users is depicted in Fig. 8. As it is expected, not only

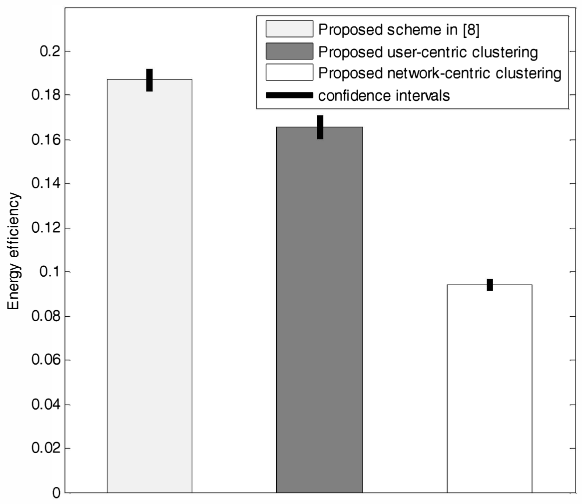
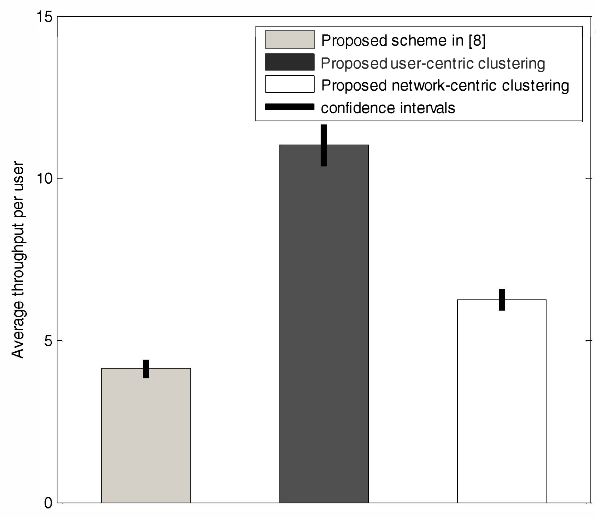
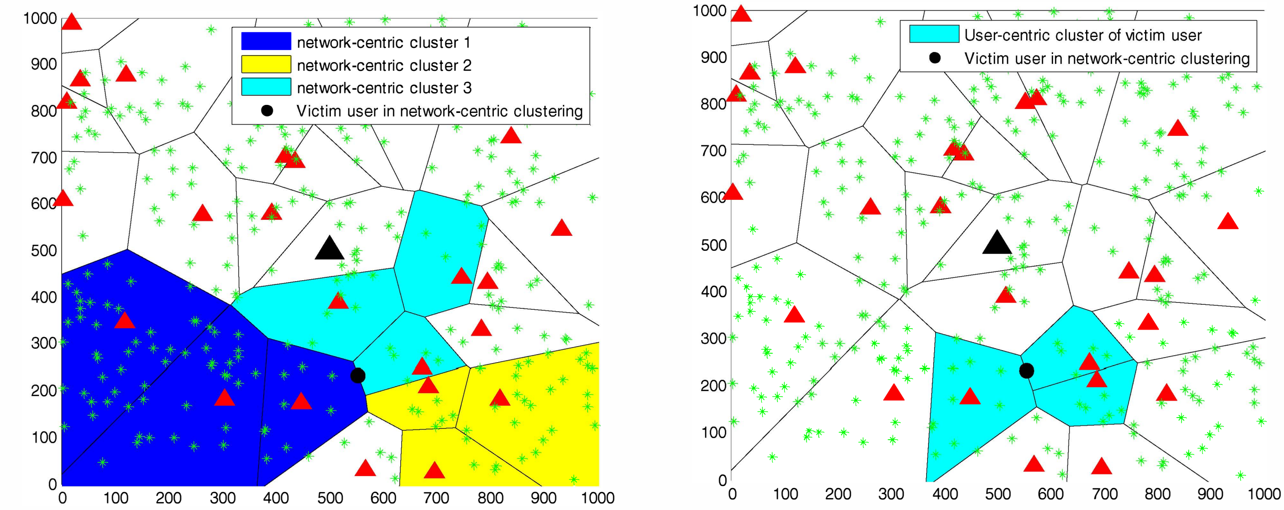


Figure 5: The effect of CoMP-JT in network energy efficiency



Figuire 6: The effect of CoMP-JT with different clustering method in provided average throughput per user



(b) (a)

Figure 7: The effect of clustering method in serving one typical user (a) user-cetric clustering approach (b) network-centric clustering approach

CoMP-JT increases the imposed load to each RRH, but also user-centric clusters have greatest effect on overloading a cell. This fact is another disadvantage of this clustering method.

VI. Conclusion and Future Works

Remarkable increase in data requirement and the necessity of offloading MeNB, made difficulties for 5G operators in satisfying the demands of all users regardless of their locations. In this paper the effect of CoMP-JT technology in enhancing network spectral efficiency and providing high data-rate demands of unsatisfied users are investigated. We also evaluate the effect of clustering method in the obtained CoMP gain. More specific, two simple user-centric and network-centric clustering algorithms are proposed and their pros and cons are discussed. Our outcomes show that conspicuous improvement in system performance could be achieved even by applying CoMP-JT in simple dynamic clusters. However, respecting to energy efficiency and imposed load to each RRH, CoMP-JT demonstrates disadvantages which should be compensated through some advisements in future investigations. In this regard, although user-centric clusters lead to better performance, they cause more energy efficiency degradation and increase cell load more as well.

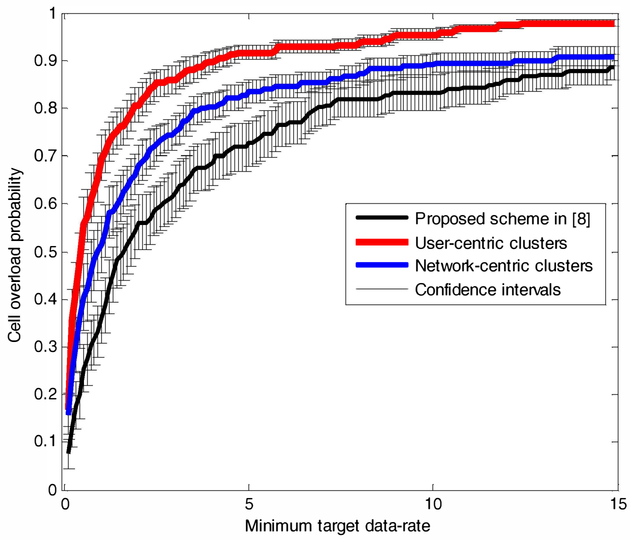


Figure 8: The effect of clustering method in cell load

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